

# Can Neutrinos Probe Extra Dimensions?

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## Abstract

We conjecture that the topological structure of the gauge symmetries required by the Calabi-Yau vacuum and the dualities in string/D-branes considered in the world with some additional dimensions can lead to an extension of the main principles of the Special Theory of Relativity. The link between the topological structure of the vacuum and the, hierarchy of the gauge symmetries could be checked by the existence of the “almost massless”, ”sterile” particles. These particles could have flying properties different from the standard predictions of the STR. It is natural to consider this property for neutrinos, known up to now “ $U(1)_{em}$  sterile” particles. Here we discuss two such effects depending on the possible existence of large and/or small extra dimensions and what is the maximal speed for both cases.

The effect of large extra dimensions can be directly connected with the existence of a hidden boost,  $c_{hid} \gg c_{em}$ , excited by new global dimensions and can lead to the monotonous rise of the neutrino velocity at high energies,  $v_\nu > c$ .

The effect of small extra dimensions, universal with respect to all particles, can be connected with the gravitation recoils of the propagation of neutrino in the space-time vacuum-foam and it leads to the effect of diminishing the neutrino velocity at high energies.

We propose to check these conjectures for neutrinos of different energies and species. Limits for existing neutrino data and expected sensitivities of possible experiments for accelerator - produced neutrinos are considered. It is pointed out that CERN has the unique opportunity of measuring the indicated effects.

# 1 Strings dualities and the origin of the gauge symmetries in the extra dimensional geometry.

Our main experience after the studies of the dualities of string/D-branes [1],[2] and the origin of the gauge symmetries [4] in the topological vacuum showed a very intriguing consequence for the geometry(extra dimensions and topology) of our ambient space-time. A topological structure of the vacuum allows to prove some dual transformations that interrelate any of the five superstring 10-dimensional theories, the M/11-dimensional supergravity and 12-dimensional F-theory with each other [3]. The proof the dual relationships among all of these theories can be done in the process of a compactification (or decompactification) on (of) the special set of these topological hypersurfaces with its very beautiful geometric topological substructure. The most intriguing inspiration of proving the string/D-brane dualities is that the “singularities” of these hypersurfaces are connected with the mechanism of the enhanced gauge symmetries and give much more deeper understanding of the origin of the gauge and chiral matter [4].

From the point of view of the topological quantum geometry the question of the compactification or/and decompactification has been already studied in the literature intensively (see, for example, [5]). From the phenomenological point of view there was only the question of the sizes of these new topological objects. Following to our goal to understand what kind of global real effects could lead to the existence of the extra topological geometry it will be important to consider separately two cases for the possible sizes of the new extra dimensions: the small (compactified) extra dimensions with the sizes determined by the scale from Plank scale till the scale of the present energies and the large (uncompactified) extra dimensions which size can reach even infinity.

The first case of the possible existence of the small (compactified) extra dimensions has been intensively studied in the literature, see for example [6]. In the case of uncompactified extra dimensions, [8] the Newton law of gravity should be overcome and this possibility can give a lot of important cosmological consequences. In this case our world can be considered, for example, as a “border-part” of the higher dimensional world with the global uncompactified 5-th or 6-th dimensions and with other 6- compactified dimensions. It is interesting to note that both cases can occur in M/F theories with  $\text{dim}=11/12$ .

An interesting example of the possible realisation of such case was found in [7] where it was shown that there is duality between the Yang-Mills  $N=4$  SUSY theory in 4-dimensions and the supergravity in 5-dimensional anti-de Sitter space. In string/D-brane approach our four-dimensional SM world could live on the world volume of a 3-brane with flat topology, which is embedded in a bulk space-time of dimension,  $D > 4$ . In this case the metrics of our world is induced by the metrics of the higher dimensional bulk space-time.

Of course, in the process of the extension of such world there could be some interrelations between the compactified and un-compactified dimensions due to shrink-down or decompactification. The process of compactification of some topological manifolds can be the origin of the Yang-Mills gauge symmetries and matter. The new uncompactified dimensions could lead to some new phenomena, to the possibility of the existence of a new matter with the different global properties with respect to the new space-time symmetries with possible new boosts. We already had one experience after the discovery the Lorentz invariance of the Maxwell equations which gave a possibility to understand the ambient Minkowski space-time with global  $SO(3, 1)$  symmetry. Kaluza and Klein understood that

the unification of the  $U(1)_{em}$  gauge symmetry and four-dimensional gravity can be naturally explained in the frame of the five-dimensional gravity where the new compactified dimension has a nontrivial topology. This link between the internal and external symmetries of vacuum, Poincare duality, could be now considered again after the discovery of the new vacuum internal symmetry,  $SU(2) \times U(1)$ , at the smaller distances. In this case due to Poincare duality there could be a link between the hierarchy of the gauge symmetries and new geometry of the space-time with the possible new dimensions and its topological structure.

There exists a very intriguing question how to check the Poincare duality and to prove the existence of these new extra dimensions. We propose to study this question through the searches of the new space-time global effects at high energies. The development of string/D-branes approach and the existence at high energies of the new vacuum symmetry,  $SU(2) \times U(1)$ , give us a chance to move forward in understanding an origin of the speed fundamental constant. Our main hope is connected with the possibilities to find a deviation for the principle of the light speed maximality,  $c = c_{em}$ , studying the flight properties of the high energy neutrinos comparing it velocity with the speed of light or with the speeds of the other charged relativistic particles.

Our proposal consists on the possibilities to check at the present accelerators the existence of the large and small extra dimensions measuring the neutrino speed at the high energy in the different scales and for different species. We conjecture that the global large (uncompactified) extra and small (compactified) dimensions could lead to the observation of the two different behaviours of the neutrino speed at high energies.

## 2 Neutrinos and large extra dimensions

We conjecture that the large new dimensions could lead directly to the observation of the effect of the monotonous rise with the energy of the neutrino velocity,  $v_\nu(E \sim E_{thr}) > c_{em}$  ( $E_{thr}$  is the energy of the  $SU(2) \times U(1)$  symmetry restoring), and could be searched by with " $U(1)_{em}$ -sterile" neutrinos of high energies. In addition to the Poincare duality, having very nice interpretation in algebraic geometry, some new arguments for the possible existence of the new symmetry with the new boost,  $c_{hid} \gg c_{em}$ , could be found from the considerations together of the modern achievements in neutrino physics, in astrophysics and cosmology, in phenomenology of the dualities in string/D-branes, in algebraic geometry of the topological hypersurfaces and its link with the origin of the gauge symmetry and matter. So, one can propose that this possibility could be realized with the following conditions:

- The existence of a new ambient geometry with new hypothetic "sterile" world connected with a possibility of the present or previous existence of a new extra dimension
- The sterile world should satisfy the own space-time symmetries incorporated a new boost  $c_{hid} \gg c_{em}$ ;

- There should exist some gauge symmetries of the sterile matter which could be linked with the observable SM -matter through neutrinos of the different species. The mechanism of the mixing between the sterile matter and neutrinos could be similar to the “sea-saw” mechanism.

So, we conjecture that the duality-symmetry between the topological structure of the vacuum and new hierarchy of the gauge symmetries:

$$U(1)_{em} \implies SU(2) \times U(1) \implies .... \quad (1)$$

should lead to an extension of the special theory of relativity based on the “one-circuit” Lorentz metrics  $g_{mn} = (-1, -1, -1, 1)$  to the new “two-circuit” metrics with the possible existence of the new boost:

$$\{SO(3, 1)\}(c_{em}) \implies \{G^{ext} \subset SO(3, 1) \times SO(1, 1) \times ... \}(c_{em}, c_{hid}) \implies ..... \quad (2)$$

Thus an extension of the Lorentz/Poincare symmetry at high energies could lead to the existence of the new hidden symmetries, like hidden boosts with the new fundamental maximal speeds,  $c_{hid}$ , ( $... \gg c_{hid} \gg c_{em}$ ), which could be checked by the existence of the “ $U(1)_{em}$ -sterile” particles. Based on the Poincare duality between the external symmetries of the ambient geometry and the internal gauge symmetry of the vacuum we propose the existence of the new hidden space-time symmetry- new hidden boost- (not necessarily the light ) excited by the extra dimensions of our world connected with the  $SU(2) \times U(1)$  vacuum symmetry. This new boost could appear, for example, from the breaking of the extra world space symmetries, like subgroup of  $SO(n, 1)$  or  $SO(n, 2)$ .

The question of the existence of the “sterile-hidden” matter has been already intensively discussed in astrophysics and cosmology during a long period. In the first condition one had suggested that this matter can produce a hidden new geometrical world including new extra dimensions with additional space-time symmetries. Of course, by this scenario the hidden matter should be concentrated mainly on the very long distances. In this case the existence of this additional symmetries should include a hidden boost with  $c_{hid} \gg c_{em}$  according to our second condition. From our knowledge of the SM the neutrinos are unique and the only particles which could have a link with the ‘sterile’ world. One might propose that the origin of the “see-saw” mechanism could also explain the link between our neutrinos and the sterile particles. Due to mixing between neutrino and sterile matter through see-saw mechanism the global flying properties of neutrino produced from the decays of the sterile matter should correspond to the space-time symmetry of the extra world. The sterile matter world should have a new mass scale higher than the electroweak scale.

As result of this link our neutrinos could “feel” the new boost,  $c_{hid}$ , and could lead to the increasing of the maximal velocity for neutrinos with restoring of the  $SU(2) \times U(1)$ -vacuum symmetry.

The model with one new hypothetical boost could be realized also through the two-metrics mechanism: one-metric action,  $S_{SM}$ , for the Standard Model based on the Lorentz/Poincare

symmetry in the  $d = 3+1$  space-time and the other action,  $S_{hid}$ , for the new sterile matter based on the new metric tensor in the space-time with extra dimensions. For the concrete model one should solve the main difficulty of finding a link between these two metrics.

The effective metrics near the threshold of the  $SU(2) \times U(1)$  symmetric vacuum, deviated from the standard dispersion relation between the energy  $E$  and the momentum  $p$  of neutrino, could be a function of the invariant production energy  $s$ , the “wind” energy  $E$  and the relation between the values of two circuit-boosts,  $c_{em}$  and  $c_{hid}$  and, may be, also depend on the neutrino species.

Such scenario with some fundamental boost-velocities could give a push to go beyond the standard Big Bang model in the time before the  $SU(2) \times U(1)$  phase and could explain the horizon, flatness problems. This scenario is different with respect to the other scenario of the varying speed of light (VSL) [9] in spite of the similar problems to construct such mechanisms.

The restriction of sterility for neutrino in our conjecture means that with the electromagnetic charged particles to observe new boost (new topological circuit) at the now available energies is very difficult or may be impossible now. By our scenario only neutrinos could be link with the sterile hidden matter action and could “feel” the second boost-speed. For  $U(1)_{em}$  charged particles “getting” to the new  $SU(2) \times U(1)$  vacuum structure could be a threshold effect like as Vavilov-Cherenkov effect with emitting of a lot of energy.

### 3 Neutrinos and small extra dimensions

The other possibility is connected with the new compactified small dimensions. It will be interesting to compare the experimental possibility of searching for the effects,  $v_\nu(E) > c_{em}$ , for neutrinos with the so called EMN effect [10] leading to the diminishing of the particle velocity  $< c_{em}$  with increasing energy. This effect is connected with the string/D-brane gravitation foam structure of the vacuum and the magnitude of this effect depends on the D/brane mass,  $M$ . It is universal for all particles and leads to the diminishing of the velocity of this particle with increasing of energy:

$$c(E) < c_{em} \quad (3)$$

To understand this point one can follow to the way suggested in papers [10] where energy dependence of the “effective” metric is the main deviation from space-time Lorentz invariance induced by the  $D$  particle recoil. It has been argued that virtual  $D$ -branes provide one possible model for space-time foam [10], and that the recoil of a  $D$  brane struck by a bosonic/fermionic closed-string particle would induce an energy-dependent modification of the background metric. Upon diagonalization of the perturbed metric, one finds a retardation in the propagation of an energetic photon/fermion :  $(\delta c/c) \sim (E/M)$  or  $(\delta c/c) \sim (E/\tilde{M})^2$ . One can also see that the correct dispersion relation between the energy  $E$  and momentum  $p$  of the massless particle in the metric background [10] is:

$$E^2 = c^2 \cdot p^2 - 2 \cdot c \cdot E \cdot (\vec{p} \cdot \vec{u}) : \quad |\vec{u}| \sim E/M \text{ or } \sim (E/\tilde{M})^2. \quad (4)$$

It has recently been pointed out that the constancy of  $c$ , the velocity of light, can be tested stringently using distant astrophysical sources that emit pulses of radiation, such

as Gamma Ray Bursts (GRBs), Active Galactic Nuclei (AGNs) and pulsars. So far, this idea has been explored by comparing the arrival times of photons of different energies  $E$  (frequencies  $\nu$ ). It has been suggested that certain quantum theories of gravity might cause variations in  $c$  that increase with  $E$  (or  $\nu$ ), possibly linearly:  $(\delta c/c) \sim (E/M)$ , or quadratically:  $(\delta c/c) \sim (E^2/\tilde{M}^2)$ , where  $M$  or  $\tilde{M}$  is a high mass scale characterizing quantum fluctuations in space-time foam. Such a linear or quadratic dependence would enable any such conjectured quantum-gravity effects to be distinguished easily (in principle) from the effects of conventional media on photon propagation and the effects of a possible photon mass, both of which would decrease with increasing energy. It is clear that in order to probe quantum-gravity effects by putting the strongest possible lower limits on  $M$  and  $\tilde{M}$ , there is a premium on distant pulsed sources that emit quanta at the highest available energy.

In this approach the mass of D- particle could be large,  $M_D \gg M_W$ , but nevertheless the correspondent reduction of the effective Lorentz metrics can be checked for neutrinos too. The example of this metrics could be important to verify the similarly ideas with the scale  $M, \tilde{M}$  not very far from the 1-Tev scale.

## 4 Experimental tests.

Awaiting for further theoretical developments of the basic structure of our World it is needed to put these conjectures under experimental checks.

In the past, the idea to measure the velocity for accelerator-produced neutrinos was stated in [11] and the subsequent experimental measurements were performed 25 years ago at the Fermilab [12]. The following upper limits at 95% CL were established

$$\begin{aligned} |\Delta\beta_{12}| &= |v_{\nu_k}/c - v_{\nu_\pi}/c| < 5 \cdot 10^{-5}, \\ |\beta_\nu - \beta_\mu| &= |\Delta\beta| < 4 \cdot 10^{-5}, \end{aligned}$$

where  $\Delta\beta = v_\nu/c - 1$ .

The idea was refreshed in 1987 [13] when the SN87A explosion was observed using photon [14] and neutrino [15] detections. The estimated upper limit is

$$|\Delta\beta| < 10^{-8}.$$

Furthermore the SN87A data can be used for estimates of differences of neutrino velocities too.

Because the 12.4 s experimental duration of the neutrino pulse[16] is compatible with expected duration of the neutrino emission during the SN87A gravitation collapse it is reasonable to take this value as an upper limit for the  $\Delta\beta_{12}$  estimate with the average neutrino energy  $\sim 10 MeV$ :

$$\Delta\beta_{12} < \Delta T/T_0 = 12.4/4.5 \cdot 10^{12} = 2.8 \cdot 10^{-12},$$

where  $T_0 = 150000$  light years.

It seems that accelerator-produced high energy neutrinos, where the flavor and the source of neutrinos are controlled, can play their own important role. Among other accelerator sites CERN has the unique opportunity with the short baseline, the long baseline and the beam-beam LHC neutrino experiments to perform systematical measurements of neutrino velocities using muon, pion and kaon, charm and beauty, W and Z decays.

The Table 1 summarizes existing results and expected sensitivity estimations of possible experiments for deviation of neutrino velocity from the speed of light. As one can see from the Table 1

- WBB and beam-dump experiments will improve the Fermilab limit for  $\nu_\mu$  from pion and kaon decays and beam-dump experiment can establish new limits for  $\nu_\mu$  and  $\nu_e$  from charm decays;
- long baseline experiments will improve the SN87A limit for  $\nu_e$  and the Fermilab limit for  $\nu_\mu$ ;
- even beam-beam LHC experiment is feasible and will establish new limits for  $\nu_\mu$  ,  $\nu_e$  and  $\nu_\tau$  from beauty, W and Z decays.

Table 1: Existing results and expected one standard deviation estimations for neutrino velocity measurements for the  $\Delta\beta_{12}$  in the case of  $v_\nu \approx c$  for one year running ( $10^7$  sec) assuming the  $\sigma = 250$  psec beam bunch filling and the  $\sigma = 200$  psec detector time resolution.

Experiment	Source of neutrino	Type of neutrino	Statistics CC events	Sensitivity of $\Delta\beta$
FNAL, NBB CCFR*) [12]	$h = \pi + k$	$\nu_\mu$		$4 \cdot 10^{-5}$
SN87A*) [16]		$\nu_e$		$1 \cdot 10^{-8}$
WBB at the WANF[?] 2 t detector, $10^{19}$ pot	$h = \pi + k$	$\nu_\mu$	400000	$1.3 \cdot 10^{-6}$
		$\nu_e$	4000	$2.2 \cdot 10^{-6}$
Beam-dump at the WANF 2 kt detector, $10^{19}$ pot	$h = \pi + k$	$\nu_\mu$	47000	$2 \cdot 10^{-6}$
		$\nu_e$	500	—
	charm	$\nu_\mu$	46000	$1.5 \cdot 10^{-6}$
		$\nu_e$	46000	$1 \cdot 10^{-6}$
beam-beam at the LHC 50 kt detector for $L = 10^{35}$ [19] 500 m flight pass	charm	$\nu_\mu$	200000	$2.5 \cdot 10^{-6}$
		$\nu_e$	200000	$2.5 \cdot 10^{-6}$
	beauty	$\nu_\mu$	30000	$2.5 \cdot 10^{-6}$
		$\nu_e$	30000	$2.5 \cdot 10^{-6}$
	$W + Z$	$\nu_\mu$	230	$1.7 \cdot 10^{-5}$
		$\nu_e$	230	$1.7 \cdot 10^{-5}$
		$\nu_\tau$	230	$1.7 \cdot 10^{-5}$
Long baseline at the NGS[18] 10 kt detector, $10^{19}$ pot	$h = \pi + k$	$\nu_\mu$	5000	$1.8 \cdot 10^{-9}$
		$\nu_e$	50	$1.8 \cdot 10^{-8}$
LBL at the NuFact[20] 10 kt detector, 3000 km, $10^{21}\mu$	$\mu$	$\nu_\mu$	14000	$3 \cdot 10^{-10}$
		$\nu_e$	14000,	$3 \cdot 10^{-10}$

\*) existing result

Below in the Table 2 we compare sensitivities of the EMN effect for neutrino velocity differences for existing and possible experiments for  $\delta\beta = E/M$  and  $\delta\beta = E^2/\tilde{M}^2$  hypothesis.

Table 2: Existing results and expected sensitivities for  $\Delta\beta_{12}$  neutrino velocity differences. Expected values are given for one year running ( $10^7$  sec) assuming the  $\sigma = 250$  psec beam bunch filling and the  $\sigma = 200$  psec detector time resolution.

Item	$E_\nu$ , MeV up point	$E_\nu$ , MeV low point	$\Delta\beta_{12}$	$M$ , GeV	$\tilde{M}$ , GeV
SN87A, KMK <sup>*)</sup>	15	7	$< 2.8 \cdot 10^{-12}$	$> 2.8 \cdot 10^9$	$> 8 \cdot 10^3$
FNAL, CCFR <sup>*)</sup>	$1.7 \cdot 10^5$	$5 \cdot 10^4$	$< 5 \cdot 10^{-5}$	$> 2.5 \cdot 10^6$	$> 2.4 \cdot 10^4$
WBB at WANF	$10^5$	$2 \cdot 10^4$	$1.8 \cdot 10^{-6}$	$4.2 \cdot 10^7$	$7 \cdot 10^4$
BD at WANF	$10^5$	$2 \cdot 10^4$	$1.4 \cdot 10^{-6}$	$5.5 \cdot 10^7$	$8 \cdot 10^4$
B-b at LHC	$2 \cdot 10^6$	$2 \cdot 10^4$	$1 \cdot 10^{-5}$	$2 \cdot 10^8$	$6 \cdot 10^5$
LBL at NGS	$3 \cdot 10^4$	$10^4$	$3.6 \cdot 10^{-9}$	$5.5 \cdot 10^9$	$5 \cdot 10^5$
NuFact	$5 \cdot 10^4$	$2 \cdot 10^4$	$4.2 \cdot 10^{-10}$	$7.1 \cdot 10^{10}$	$2.2 \cdot 10^6$

\*) existing result

As one can see the long baseline experiments can exceed the SN87A low limit for the  $\delta\beta = E/M$  hypothesis and all accelerator experiments are more sensitive than the SN87A for the  $\delta\beta = E^2/\tilde{M}^2$  hypothesis.

As it was pointed out in section 2 the sterile matter should be heavy and therefore it could be the source of the very high energy neutrinos from far ends of our “visible” Universe. If, for example, such astrophysical objects like GRBs or/and AGNs satisfy the conditions for the sterile matter creation then they could be a source for neutrinos with velocities exceeding the speed of light. Due to huge distances from these objects the sensitivity  $\Delta\beta \sim 10^{-16}$  can be reached [21].

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